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A note on Cole and Stockman

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1 Introduction

Cole and Stockman (1992) develop a differentiated product model with endogenous specialization and money, and contrast its results with the usual cash-in-advance models' results, where specialization is exogenous. In their derivation of the first order conditions, they overlook a necessary discontinuity on the consumption profile and, consequently, get non-accurate results. In this note we redo their derivation and show where their results fail. In particular, the equation determining the degree of specialization (equation 24, page 290) misses several important terms. Their equation is only accurate in the limit case of zero interest rate (and full specialization), which is the only case where the consumption profile is not discontinuous.

The reason why we found the problem just mentioned is that one proposition, reported in Pessoa (2003), that we believe is quite general, was not valid for Cole and Stockman's model. We therefore show that the proposition is indeed valid once one uses the corrected version of Cole and Stockman's equations. The proposition is that the welfare cost of inflation is given by the area below the compensated money demand function (that is, it is a formalization of Bailey's rule). In addition, we also show that any distortion that locally increase the money demand is welfare improving, regardless of any other effect it may cause. A straightforward consequence of this result, once we consider the extension of their model with the inclusion of an alternate transaction technology (ATT), is a necessary and sufficient condition for overbanking in their model. That is, there is too much ATT (or too much banking) from a welfare perspective if and only if a tax on

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ATT increase the money demand. Given that such a tax necessarily decreases ATT demand, one can expect the overbanking result.

2 The Problem

Cole and Stockman's model is as follows. There is a continuum of agents and a continuum of goods. One individual can either produce any given good, or buy it from someone else using money. Hence the cash-in-advance restriction only applies to a subset of the goods, the ones the individual purchases. Given the assumption of gains to specialization, inflation reduces efficiency as it induces individuals not to fully specialize (they would rather produce some of the goods to avoid the opportunity cost of having to hold money to buy those goods).

Formally, for a given individual, $C_t(i) = c_t(i) + c_t^*(i)$ is his consumption on good $i \in [0, 1]$ at time t , where $c_t(i)$ represents the consumption of a home produced good i and $c_t^*(i)$ represents the consumption of a purchased good i . Also, $L_t(i)$ represents his labor effort to produce good i at time t . His preferences are then given by

$$\sum_{t=0}^{\infty} \beta^t \left[\int_0^1 U(C_t(i)) di - h \left(\int_0^1 L_t(i) di \right) \right], \quad (1)$$

where $U(\cdot)$ is strictly concave and satisfies Inada conditions, and $h(\cdot)$ is strictly convex. All individuals are assumed identical. The degree of specialization is denoted by α_t where

$$\alpha_t = \int_0^1 \mathbf{1}_{\{L_t(i) > 0\}} di, \quad (2)$$

that is, it is the range of goods produced by the individual. Gains to specialization are captured by having the output of one's labor effort given by

$$y_t(i) = f(\alpha_t) L_t(i)$$

with $f(\cdot)$ decreasing and concave.

The individual maximizes (1) subject to the following constraints

$$c_t(i) \leq y_t(i) \quad (3)$$

$$\int_0^1 p_t(i) c_t^*(i) di \leq M_t \quad (4)$$

$$(B_t - (1 + R_{t+1})B_{t-1} + M_t - (M_{t-1} + \tau_t))/p_t \leq \int_0^1 (y_t(i) - C_t(i)) di, \quad (5)$$

where $p_t(i)$ is the price of good i at time t , M_t and B_t are the individual money and bond holdings at time t , R_t is the interest rate at time t and τ_t is a transfer of money that the individual receives at the beginning of the period (τ_t equals $M_t - M_{t-1}$, and the money supply M_t is assumed to follow an exogenous stochastic process). Constraint (3) is self-explanatory, constraint (4) is the cash-in-advance restriction, and (5) is the budget constraint (symmetry ensures that $p_t(i) = p_t$ for all $i \in [0, 1]$).

Inada conditions and (3) imply that

$$[c_t(i), c_t^*(i), C_t(i)] = \begin{cases} [c_t, 0, c_t] & \text{for } i \in [0, \alpha_t] \\ [0, c_t^*, c_t^*] & \text{for } i \in (\alpha_t, 1), \end{cases} \quad (6)$$

i.e., that goods indexed by $i \in [0, \alpha_t]$ are self-produced and the remaining are purchased (cash) goods. It follows that the consumption profile $c(i)$ is discontinuous at $i = \alpha_t$. Hence, the optimization problem above is not entirely standard. Denoting the multipliers associated with (3)-(5) by $\theta_t(i)$, δ_t and Γ_t , we can write the following Lagrangian¹

$$\begin{aligned} \mathcal{L} = & \sum_{t=0}^{\infty} \beta^t \left\{ \int_0^{\alpha_t} U(C_t(i)) di + \int_{\alpha_t}^1 U(C_t(i)) di - h(\alpha_t L_t) + \int_0^{\alpha_t} \theta_t(i) [f(\alpha_t) L_t - c_t(i)] di \right. \\ & + \int_{\alpha_t}^1 \theta_t(i) c_t(i) di + \Gamma_t \left[f(\alpha_t) \alpha_t L_t - \int_0^{\alpha_t} C_t(i) di - \int_{\alpha_t}^1 C_t(i) di \right. \\ & \left. \left. - (B_t - (1 + R_{t-1}) B_{t-1} + M_t - M_{t-1} - \tau_t) \frac{1}{p_t} \right] \right. \\ & \left. + \delta_t \left[\frac{M_{t-1} + \tau_t}{p_t} - \int_0^{\alpha_t} c_t^*(i) di - \int_{\alpha_t}^1 c_t^*(i) di \right] \right\}, \end{aligned} \quad (7)$$

from which we get that the first order condition for the choice of α_t is given by

$$\begin{aligned} 0 = & \lim_{i \rightarrow \alpha_t^-} U(C_t(i)) - \lim_{i \rightarrow \alpha_t^+} U(C_t(i)) - L_t h'(\alpha_t L_t) + \int_0^{\alpha_t} \theta_t(i) f'(\alpha_t) L_t di \\ & + \lim_{i \rightarrow \alpha_t^-} \theta_t(i) [f(\alpha_t) L_t - c_t(i)] - \lim_{i \rightarrow \alpha_t^+} \theta_t(i) c_t(i) \\ & + \Gamma_t \left[\alpha_t f'(\alpha_t) L_t + f(\alpha_t) L_t - \lim_{i \rightarrow \alpha_t^-} C_t(i) + \lim_{i \rightarrow \alpha_t^+} C_t(i) \right] \\ & - \delta_t \left(\lim_{i \rightarrow \alpha_t^-} c_t^*(i) - \lim_{i \rightarrow \alpha_t^+} c_t^*(i) \right). \end{aligned} \quad (8)$$

¹They assume that $L_t(i) = L_t$ and get rid of the second integral on (1).

The other first order conditions are the ones reported in Cole and Stockman. In particular, we can use

$$\Gamma_t = U'(c_t) \text{ and } \Gamma_t(1 + R_t) = U'(c_t^*), \quad (9)$$

and substitute (6) into (8) to get:

$$\begin{aligned} 0 = & U(c_t) - U(c_t^*) - L_t h'(\alpha_t L_t) + \int_0^{\alpha_t} \theta_t(i) f'(\alpha_t) L_t di + \lim_{i \rightarrow \alpha_t^-} \theta_t(i) [f(\alpha_t) L_t - c_t] - 0 \\ & + \Gamma_t [\alpha_t f'(\alpha_t) L_t + f(\alpha_t) L_t - c_t + c_t^*] - \delta_t (0 - c_t^*). \end{aligned} \quad (10)$$

Also, the first order conditions imply that

$$\theta_t(i) = \begin{cases} 0 & \text{for } i \in [0, \alpha_t] \\ \delta_t = \Gamma_t R_t & \text{for } i \in (\alpha_t, 1), \end{cases}$$

so that we can rewrite (10) as

$$0 = U(c_t) - U(c_t^*) - L_t h'(\alpha_t L_t) + \Gamma_t [\alpha_t f'(\alpha_t) L_t + f(\alpha_t) L_t - c_t + c_t^*] + \Gamma_t R_t c_t^*,$$

or

$$0 = U(c_t) - U(c_t^*) - L_t h'(\alpha_t L_t) + \Gamma_t [\alpha_t f'(\alpha_t) L_t + f(\alpha_t) L_t - c_t + (1 + R_t) c_t^*]. \quad (11)$$

The equivalent to (11) in Cole and Stockman is their equation 24 at page 290, which we reproduce here

$$\theta(\alpha_t) f(\alpha_t) L_t + \Gamma_t \alpha_t f'(\alpha_t) L_t = 0. \quad (\text{CS-24})$$

Clearly, several terms included in (11) are missing in their equation. Still, the interpretation of (11) is straightforward. A marginal increase in the range of goods produced by the household from α_t to $\alpha_t + d\alpha_t$ has the following net impact on instantaneous utility:

$$[U(c_t) - U(c_t^*) - L_t h'(\alpha_t L_t)] d\alpha_t.$$

There is an increase in utility of $(U(c_t) - U(c_t^*)) d\alpha_t$ because of the increased consumption of the home produced good, and also a decrease in utility of $L_t h'(\alpha_t L_t) d\alpha_t$ due to higher labor effort, for a given per good labor effort L_t . On the other hand, the same marginal increase in the range of goods

produced by the household has the following net impact on the household's budget constraint:

$$[\alpha_t f'(\alpha_t)L_t + f(\alpha_t)L_t - c_t + (1 + R_t)c_t^*] d\alpha_t.$$

The term $f(\alpha_t)L_t d\alpha_t$ captures the increase in production and the term $\alpha_t f'(\alpha_t)L_t d\alpha_t$ captures the decrease in production, due to the reduction in specialization, so that $[\alpha_t f'(\alpha_t)L_t + f(\alpha_t)L_t] d\alpha_t$ is the net impact on production. In addition, $[-c_t + (1 + R_t)c_t^*] d\alpha_t$ is the net impact on purchases. The household saves $(1 + R_t)c_t^* d\alpha_t$ and increases consumption by $c_t d\alpha_t$. Equation (11) sets the net impact on instantaneous utility equal to the net impact on the budget constraint.

If $R_t = 0$, then there would be no discontinuity in $c(i)$ and, consequently, the first order conditions derived in Cole and Stockman would be correct. Indeed, (11) above would reproduce their equation 24. But this would be a limit situation, not the generic one.

3 Applications

3.1 Welfare Cost of Inflation

As mentioned above, we came upon the mistake in Cole and Stockman's paper while trying to show one result, which is stated in the Claim 1 below. We state and prove it, using our equation (11). We have not been able to show it using their equation 24.

Claim 1 *Defining the welfare cost of perfect foreseen inflation as the income that should be given to the household in order to compensate her for the harm caused by inflation, then if inflation is the unique distortion in the economy, the welfare cost of inflation is exactly equal to the area under the inverse compensated money demand function.*

This result is shown to be very general in Pessôa (2003). In fact, there it is shown that the result holds for a broad variety of monetary models, including the Sidrauski and the cash-in-advance models.

Proof. Considering a constant nominal interest rate, one can write the indirect intertemporal utility function as

$$V(R) = \sum_{t=0}^{\infty} \beta^t [\alpha_t u(c_t) + (1 - \alpha_t)u(c_t^*) - h(\alpha_t L_t)],$$

from which we get

$$\begin{aligned} \frac{dV(R)}{dR} = & \sum_{t=0}^{\infty} \beta^t \left[\alpha_t u'(c_t) \frac{dc_t}{dR} + (1 - \alpha_t) u'(c_t^*) \frac{dc_t^*}{dR} + (u(c_t) - u(c_t^*)) \frac{d\alpha_t}{dR} \right. \\ & \left. - h'(\alpha_t L_t) \left(\alpha_t \frac{dL_t}{dR} + L_t \frac{d\alpha_t}{dR} \right) \right]. \end{aligned} \quad (12)$$

From the market equilibrium equation we know that

$$\alpha_t c_t + (1 - \alpha_t) c_t^* - \alpha_t f(\alpha_t) L_t - e_t = 0,$$

where e_t is an endowment that is going to be the measure of the welfare cost of inflation (that is, if inflation increases this endowment has to increase in order to compensate the household for the harm caused by inflation).

Consequently

$$\begin{aligned} 0 = & - \sum_{t=0}^{\infty} \beta^t u'(c_t) \left[\alpha_t \frac{dc_t}{dR} + (1 - \alpha_t) \frac{dc_t^*}{dR} - \alpha_t f(\alpha_t) \frac{dL_t}{dR} \right. \\ & \left. + (c_t - c_t^* - f(\alpha_t) L_t - \alpha_t f'(\alpha_t) L_t) \frac{d\alpha_t}{dR} - \frac{de_t}{dR} \right]. \end{aligned} \quad (13)$$

Adding (12) and (13)

$$\begin{aligned} \frac{dV(R)}{dR} = & \frac{dV(R)}{dR} + 0 = \sum_{t=0}^{\infty} \beta^t \left\{ (1 - \alpha_t) [u'(c_t^*) - u'(c_t)] \frac{dc_t^*}{dR} \right. \\ & + [u(c_t) - u(c_t^*) - h'(\alpha_t L_t) L_t \\ & - u'(c_t)(c_t - c_t^* - f(\alpha_t) L_t - \alpha_t f'(\alpha_t) L_t)] \frac{d\alpha_t}{dR} \\ & \left. - \alpha_t [h'(\alpha_t L_t) - u'(c_t) f(\alpha_t)] \frac{dL_t}{dR} + u'(c_t) \frac{de_t}{dR} \right\}. \end{aligned} \quad (14)$$

Substituting (11) into (14), and using

$$\begin{aligned} h'(\alpha_t L_t) - u'(c_t) f(\alpha_t) &= 0 \\ u'(c_t^*) - u'(c_t) &= R u'(c_t), \end{aligned}$$

it follows that

$$\frac{dV(R)}{dR} = \sum_{t=0}^{\infty} \beta^t \left\{ (1 - \alpha_t) u'(c_t) R \frac{dc_t^*}{dR} - R c_t^* u'(c_t) \frac{d\alpha_t}{dR} \right\} + \sum_{t=0}^{\infty} \beta^t u'(c_t) \frac{de_t}{dR}.$$

If the household is compensated, then we must have $\frac{dV(R)}{dR} = 0$, which means that

$$\sum_{t=0}^{\infty} \beta^t u'(c_t) \left\{ (1 - \alpha_t) R \frac{dc_t^*}{dR} - R c_t^* \frac{d\alpha_t}{dR} \right\} = - \sum_{t=0}^{\infty} \beta^t u'(c_t) \frac{de_t}{dR}.$$

Since there is no capital in this economy, there is no dynamics after a change in the nominal interest rate either. Consequently, we can drop the index t and calculate explicitly the infinite sum:

$$\begin{aligned} \frac{de}{dR} &= -R \left[(1 - \alpha) \frac{dc^*}{dR} - c^* \frac{d\alpha}{dR} \right] \\ &= -R \frac{dm}{dR}, \end{aligned}$$

where $m = (1 - \alpha)c^*$ due to the cash-in-advance constraint. Integrating $\frac{de}{dR}$ gives

$$\text{Welfare Cost of Inflation} = e = - \int_{-\rho}^R x \frac{dm}{dx} dx = \int_{m(R)}^{m(-\rho)} x(m) dm$$

where $1 + \rho = \frac{1}{\beta}$. Since $x(m)$ is the compensated money demand, we are done. ■

3.2 Overbanking

Cole and Stockman also extend their model to include an alternative transactions technology (ATT), which captures any form of payment other than money (like credit cards for instance). We can think of it as representative of the services provided by a banking sector to help the individuals cope with inflation. There is a cost $\sigma(x)$ of acquiring x units of output through ATT, where $\sigma(0) = 0$ and σ is strictly increasing and convex. Let $z_t(i)$ be the number of goods of type i that the individual acquires through ATT. The only equations that change are (1) and (5) which become

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\int_0^1 U(C_t(i) + z_t(i)) di - h(\alpha_t L_t + \sigma(\int_0^1 z_t(i) di)) \right]$$

and

$$(B_t - (1 + R_{t+1})B_{t-1} + M_t - (M_{t-1} + \tau_t))/p_t \leq f(\alpha_t)\alpha_t L_t - \int_0^1 (C_t(i) + z_t(i))di.$$

The first-order conditions reported in their paper for the extended model also overlook the discontinuity in the consumption profile. It is possible to redo their computations, and then follow the steps in the proof of Claim 1 above to show that

$$\left. \frac{dV}{d\tau} \right|_{\tau=0} = \sum_{t=0}^{\infty} \beta^t \left. \frac{dm_t}{d\tau} \right|_{\tau=0}, \quad (15)$$

where τ is any purchase tax. In particular, if τ is a tax on the ATT and if the introduction of this tax increases money demand equation (15) says that there is overbanking. A tax discouraging ATT increases utility by increasing money demand. Note that this result does not depend on the nature of the impact of τ on variables other than money demand. It is likely that the introduction of τ generates other distortions that affect welfare. Equation (15) shows that these effects are negligible at first-order.

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